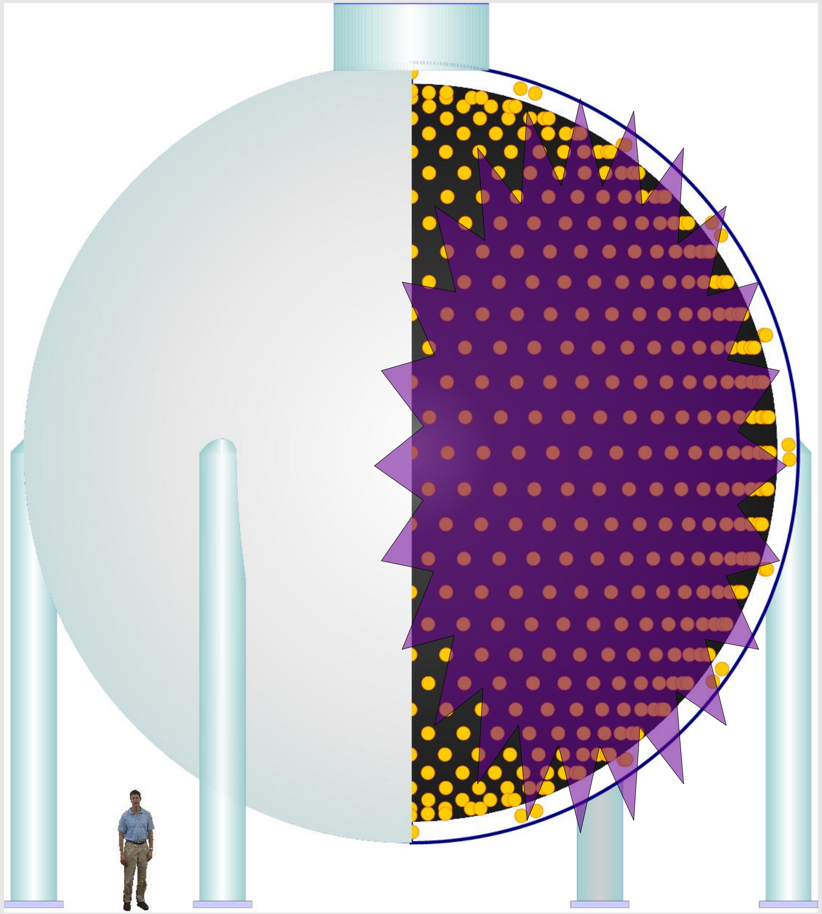
P-1033: LOI for future running of MiniBooNE with scintillator

"A new investigation of $\nu_\mu \rightarrow \nu_e$ oscillations with improved sensitivity in an enhanced MiniBooNE experiment"

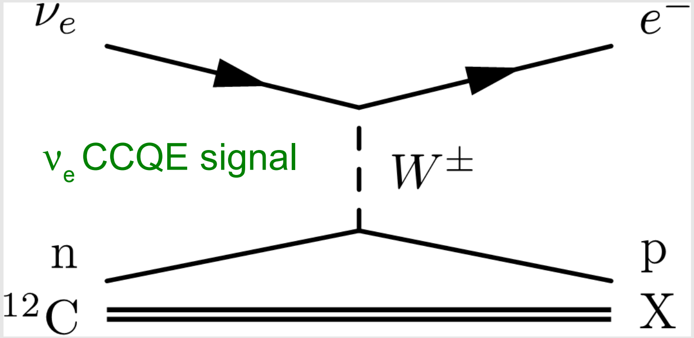


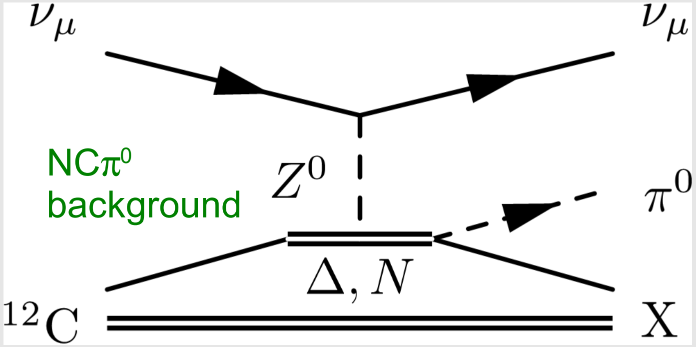
Outline:
- Overview
- Physics
- Increasing scintillation
- Reconstruction/analysis
- Sensitivity
- plans/request/summary

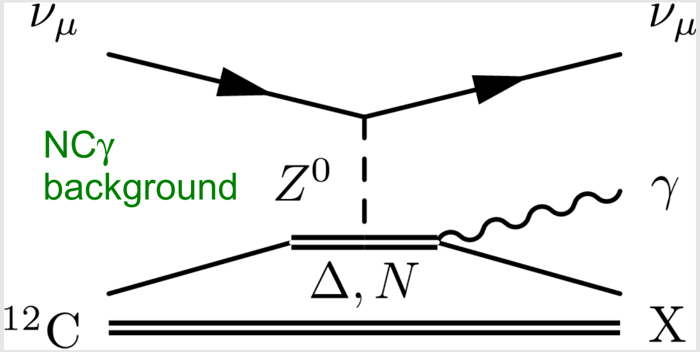
Overview

We propose the addition of scintillator to MiniBooNE to enable reconstruction of 2.2 MeV n-capture photons for an enhanced $\nu_\mu \rightarrow \nu_e$ search at low energy.

The n-capture ($np \rightarrow d\gamma$) signal will enable separation of CC oscillation signal events from NC backgrounds for an improved test of the low-energy MiniBooNE oscillation excess.







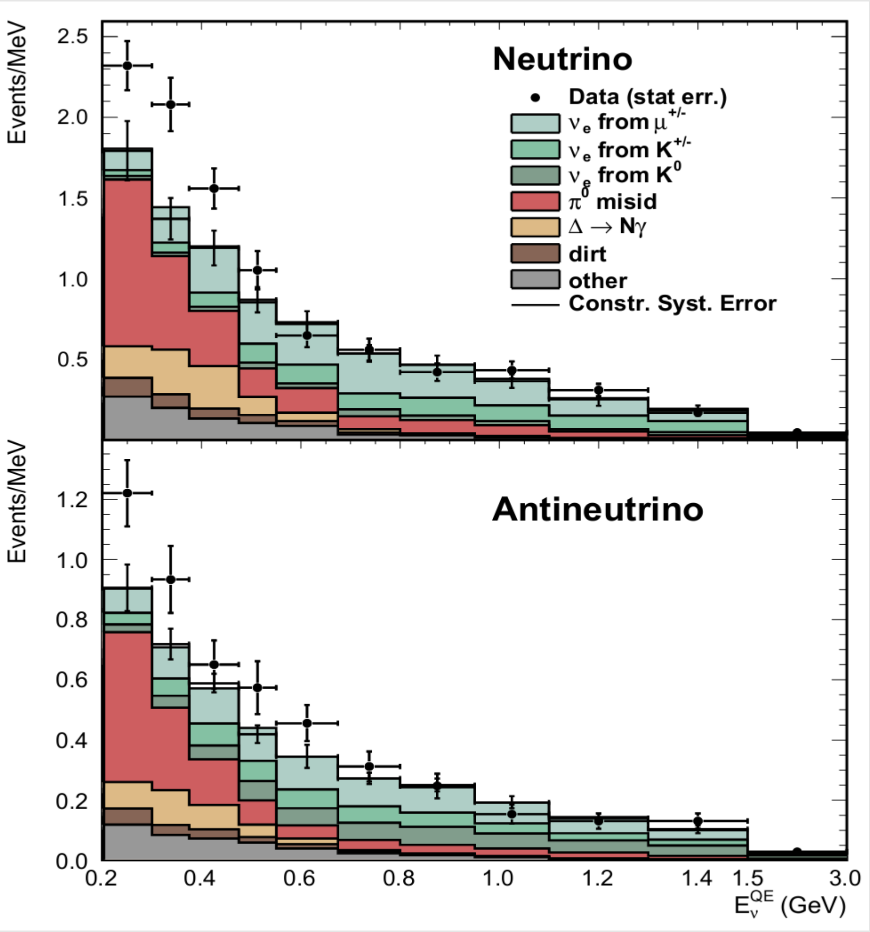
Other physics channels opened:

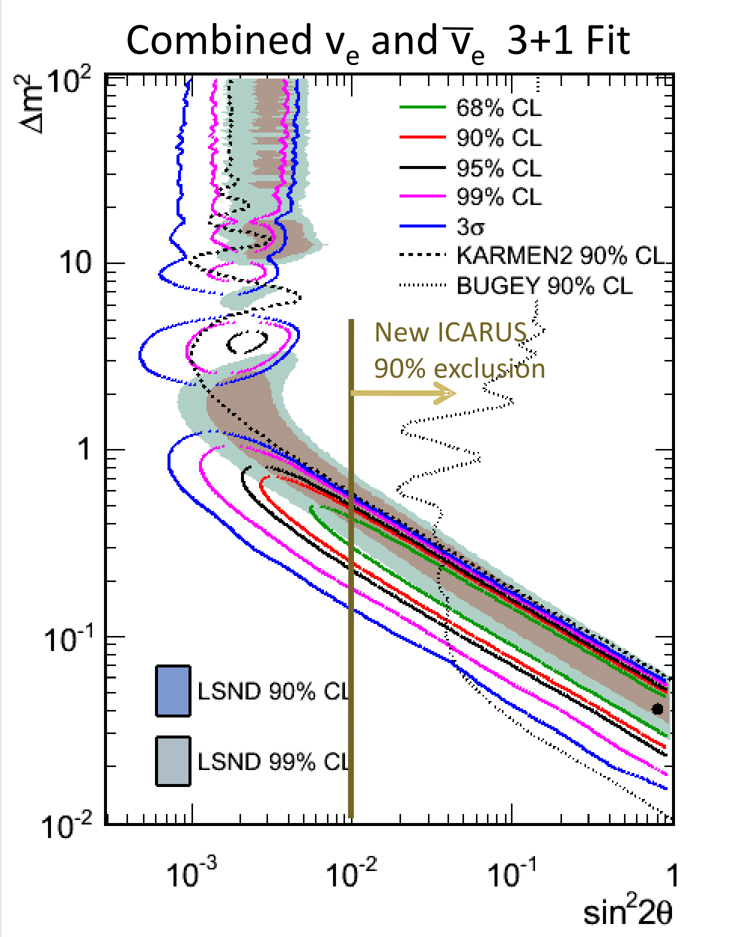
- p to n ratio in NC elastic scattering (Δs)
- measurement of $\nu_\mu C \rightarrow \mu^- N_{g.s.}$
- a test of QE assumption in neutrino energy reconstruction

This program of measurements requires approximately 6.5×10^{20} protons on target delivered to MiniBooNE and can begin in early 2014. We are requesting support of this concept to enable the collaboration to plan the experiment and analysis in more detail with the goal of submitting a full proposal for the experiment in mid-2013.

MiniBooNE oscillation excess:

- The combined $\nu/\bar{\nu}$ data set (including all $\bar{\nu}$ data to date) yields a combined excess of 240.3±62.9 events (3.8σ) and is consistent with LSND.





- Excess occurs mostly at low-energy where NCγ and NCπ^0 are dominant. So it is natural to examine these backgrounds further.

MiniBooNE oscillation NC backgrounds:

- Both NCγ and NCπ^0 are constrained with additional MB measurements.
  - NCπ^0 directly measured in MB
  - NCγ constrained to NCπ^0 (due to dominance of Δ, $\Delta \rightarrow N\gamma$)

- Recent theoretical calculations agree with MB calculations

B. D. Serot and X. Zhang, arXiv:1110.2760 [nucl-th].

B. D. Serot and X. Zhang, Phys. Rev. C **86**, 015501 (2012) [arXiv:1206.3812 [nucl-th]].

X. Zhang and B. D. Serot, arXiv:1208.1553 [nucl-th].

X. Zhang and B. D. Serot, arXiv:1206.6324 [nucl-th], accepted to Physical Review C.

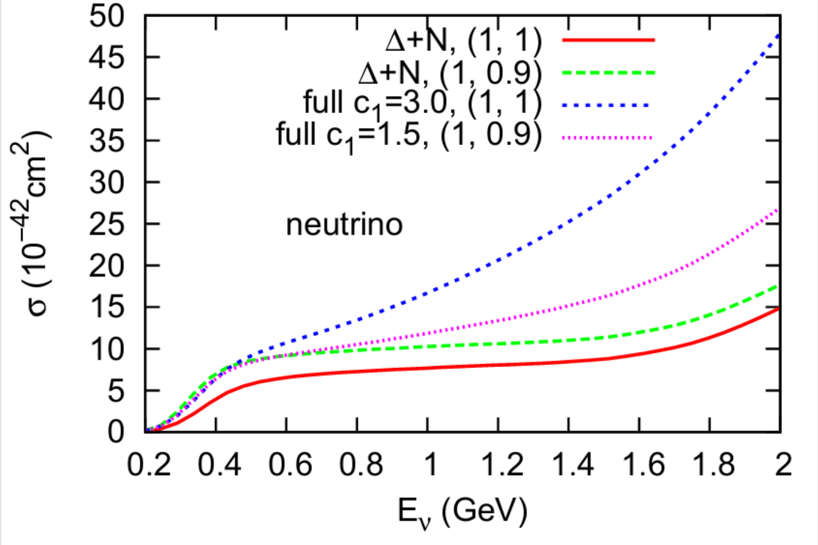
J. A. Harvey, C. T. Hill and R. J. Hill, Phys. Rev. Lett. **99**, 261601 (2007) [arXiv:0708.1281 [hep-ph]].

R. J. Hill, Phys. Rev. D **81**, 013008 (2010) [arXiv:0905.0291 [hep-ph]].

X. Zhang and B. D. Serot, in Press.

R. J. Hill, Phys. Rev. D **84**, 017501 (2011) [arXiv:1002.4215 [hep-ph]].

NCγ production cross section



From Zhang and Serot, In press.

E_{QE}(GeV)	[0.2 , 0.3]	[0.3 , 0.475]	[0.475 , 1.25]
coh	1.3 (2.4)	6.4 (9.9)	2.4 (9.3)
inc	9.5 (10.5)	27.6 (31.3)	16.7 (27.1)
H	3.0 (3.3)	10.6 (11.7)	5.4 (7.4)
Total	13.8 (16.2)	44.6 (52.9)	24.5 (43.8)
MiniBN	19.5	47.3	19.4
Excess	42.6 ± 25.3	82.2 ± 23.3	21.5 ± 34.9

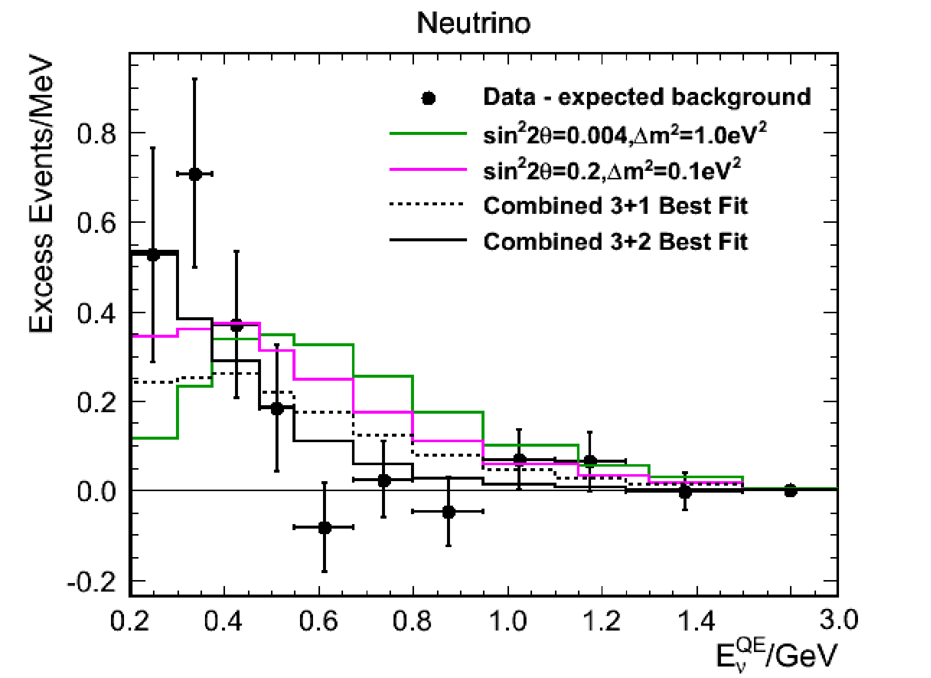
TABLE II: E_{QE} distribution of the NC photon events in the MiniBooNE neutrino run, comparing our estimate to the MiniBooNE estimate [1].

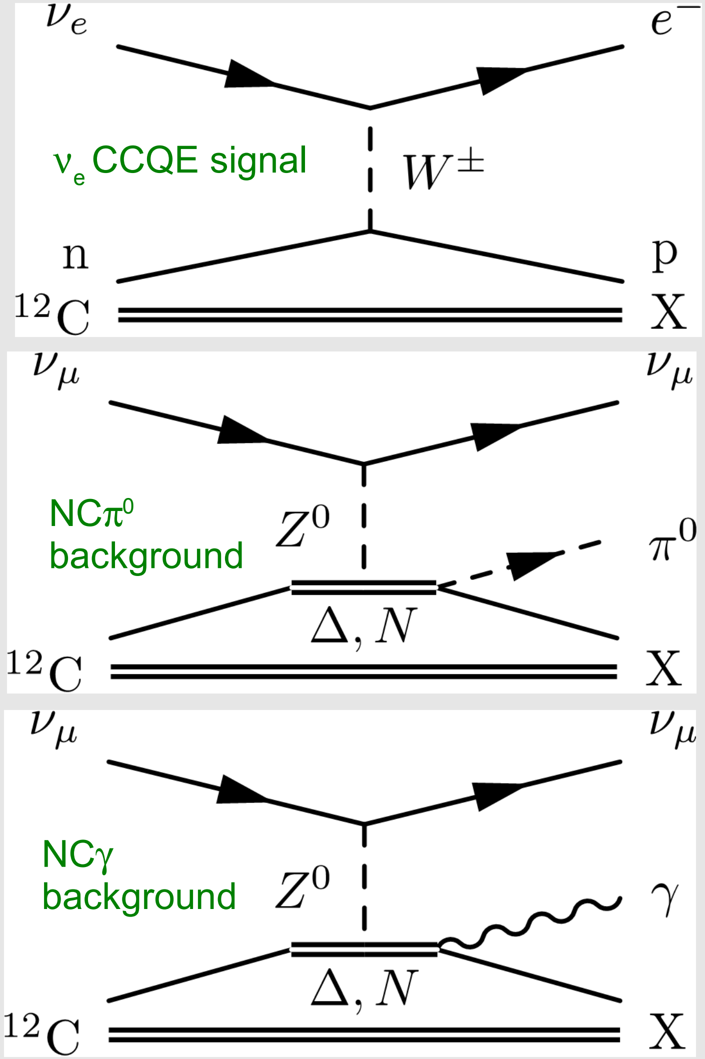
Physics: $\nu_\mu \rightarrow \nu_e$ search with NC tag

Select oscillation candidates with an associated n-capture "tag".
If event excess (at low energy) is:

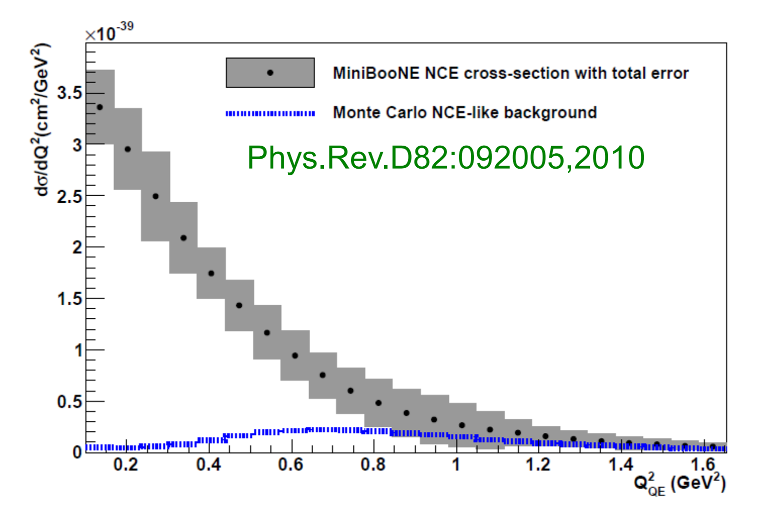
- CC oscs: excess will disappear since it is mostly CCQE (with only 1-10% neutrons)

- NC bckgd: excess will not disappear since it will contain 50% neutrons. This is because of dominance of NC Δ with equal branch to p/n decay





More physics opportunities



NC elastic scattering:

- MiniBooNE has measured ν – nucleon NC elastic scattering in both ν and $\bar{\nu}$ channels.
- Addition of scintillator allows for n/p separation and measurement of Δs (s-quark contribution to nucleon spin) via:

$$R(NCp/NCn) = \frac{\sigma(\nu_\mu p \rightarrow \nu_\mu p)}{\sigma(\nu_\mu n \rightarrow \nu_\mu n)}$$

$$\frac{d\sigma}{dQ^2}(\nu N \rightarrow \nu N) \propto (-\tau_z G_A + G_A^s)^2$$

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$

$$\Delta q = q\uparrow - q\downarrow + \bar{q}\uparrow - \bar{q}\downarrow$$

$$G_A^s(Q^2=0) = \Delta s$$

for more input to ongoing proton spin puzzle.

- Measurement of $\nu_\mu C \rightarrow \mu^- N_{g.s.}$
  - tagged with $N_{g.s.}$ β decay (~15MeV endpoint, enabled with scintillator)
  - cross section known to ~2% near threshold allows a low-E flux test

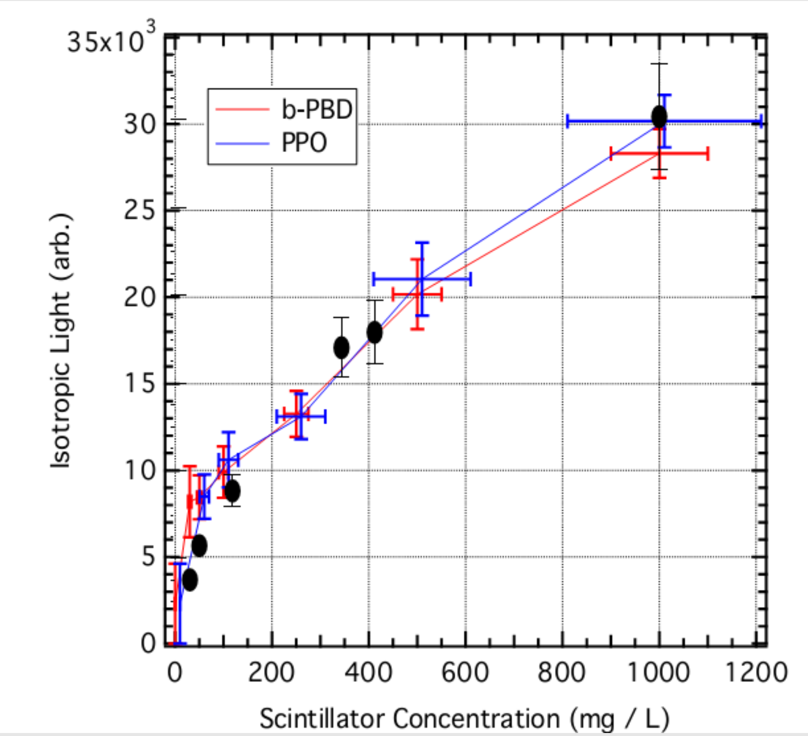
- Test of E_ν^{QE} in ν energy reconstruction
  - addition of scintillator will allow total energy of event to be measured and compared with E_ν^{QE}, the current method of reconstruction that assumes quasielastic ν–nucleon scattering.

Adding scintillator

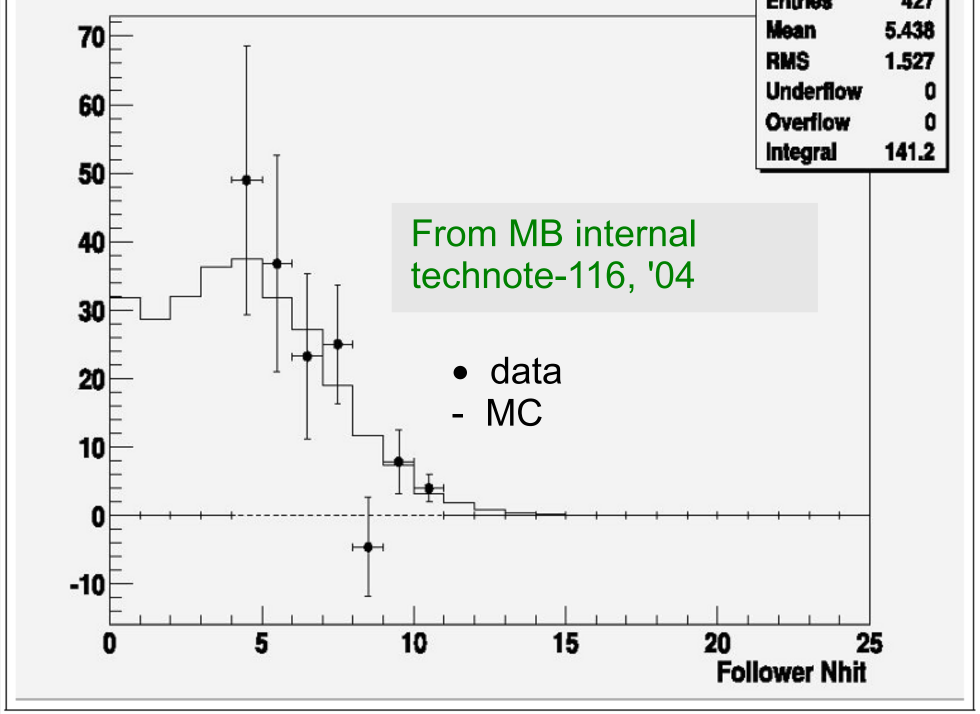
Currently MiniBooNE observes ~5 PMT hits from n-capture (np→dγ(2.2MeV), τ~186μs).

n-capture has been observed in early data studies, simulated correctly with MC.

Desire for this to increase to ~25 PMT hits to enable good position recon of n-capture event and correlation with primary.



MiniBooNE n-capture study



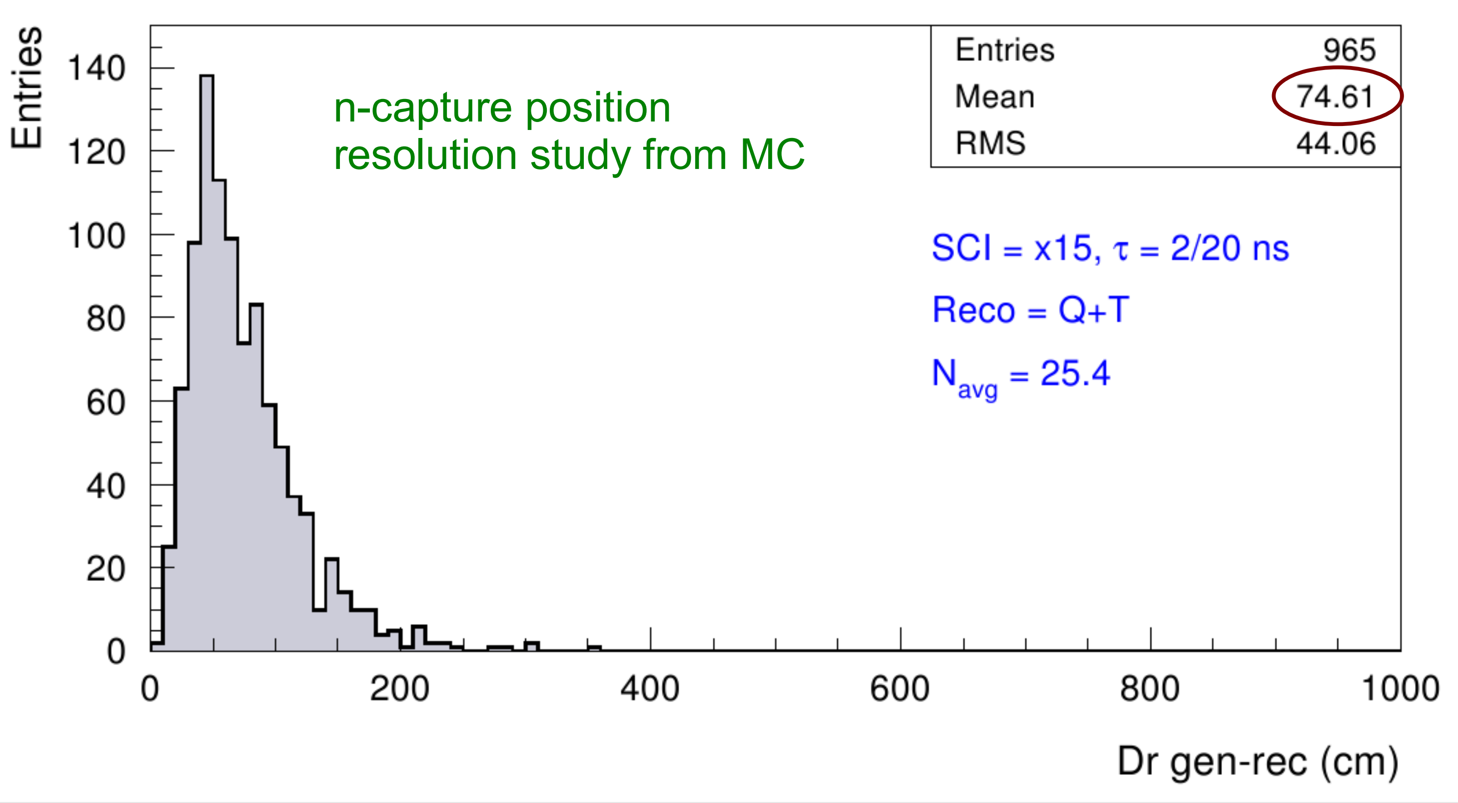
From MC studies combined with lab tests, determined that 300kg of PPO (~$75k) added to 800 tons MiniBooNE mineral oil (0.3g/l) will increase light to desired level.

Event reconstruction

Have studied event reconstruction with
- current simulation with addtion of scintillator model
- existing reconstruction algorithms, minimally modified for this change.

- 2.2 MeV γ reconstruction yields good position resolution, with only 1st order changes for

- Will allow good efficiency and background rejection for 2.2 MeV γ correlated to ν osc.event



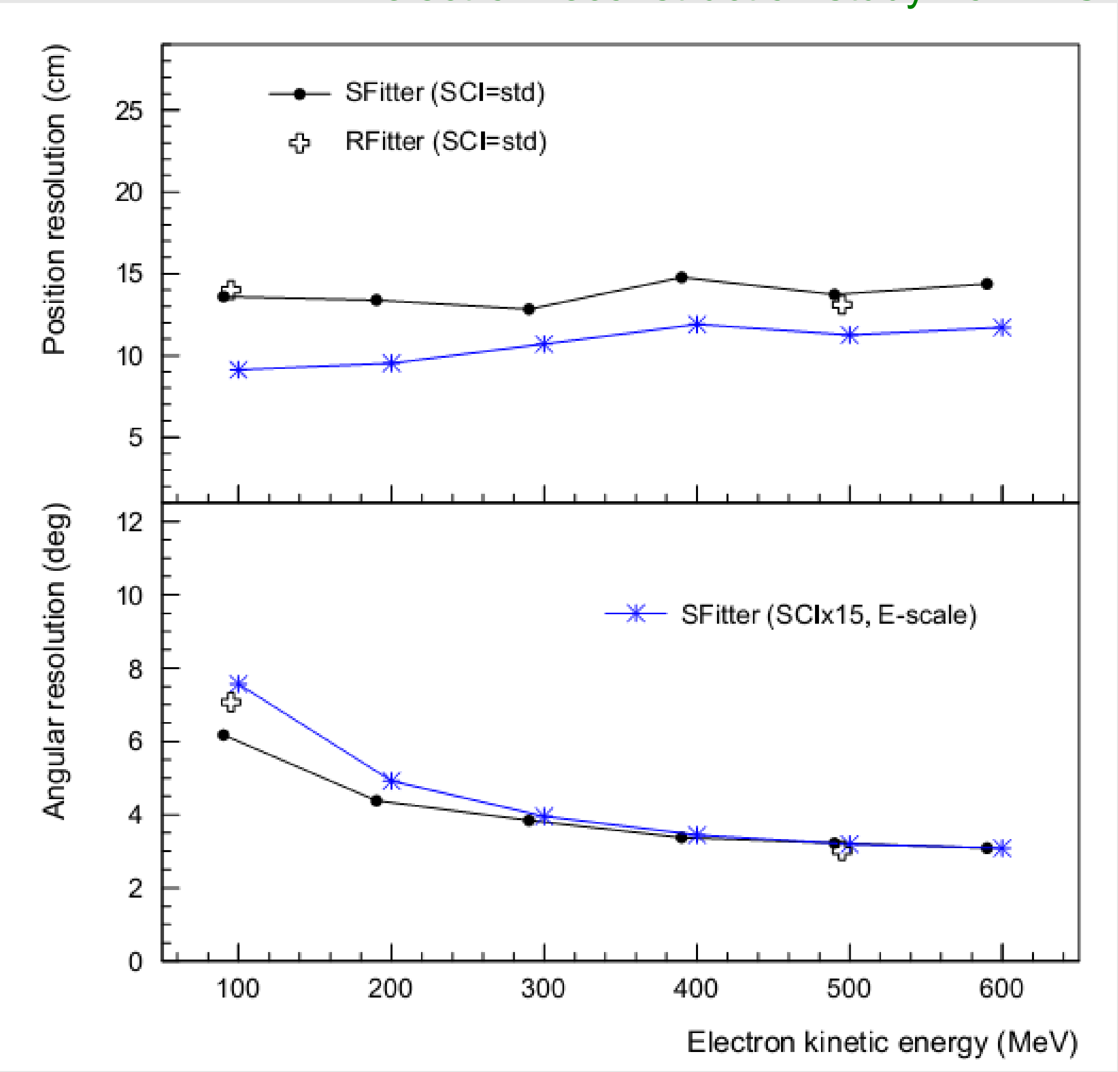
Event reconstruction

Also require good reconstruction of e, μ, π^0 to conduct oscillation search with scintillator.

Studies to date show that electron reconstruction is still good, at least to ~500MeV, with only moderate tuning of algorithms.

Need to also show good particle ID with signal/background separation comparable to previous to allow oscillation analysis after addition of scintillator. Important, work in progress.

electron reconstruction study from MC



Simulated Analysis

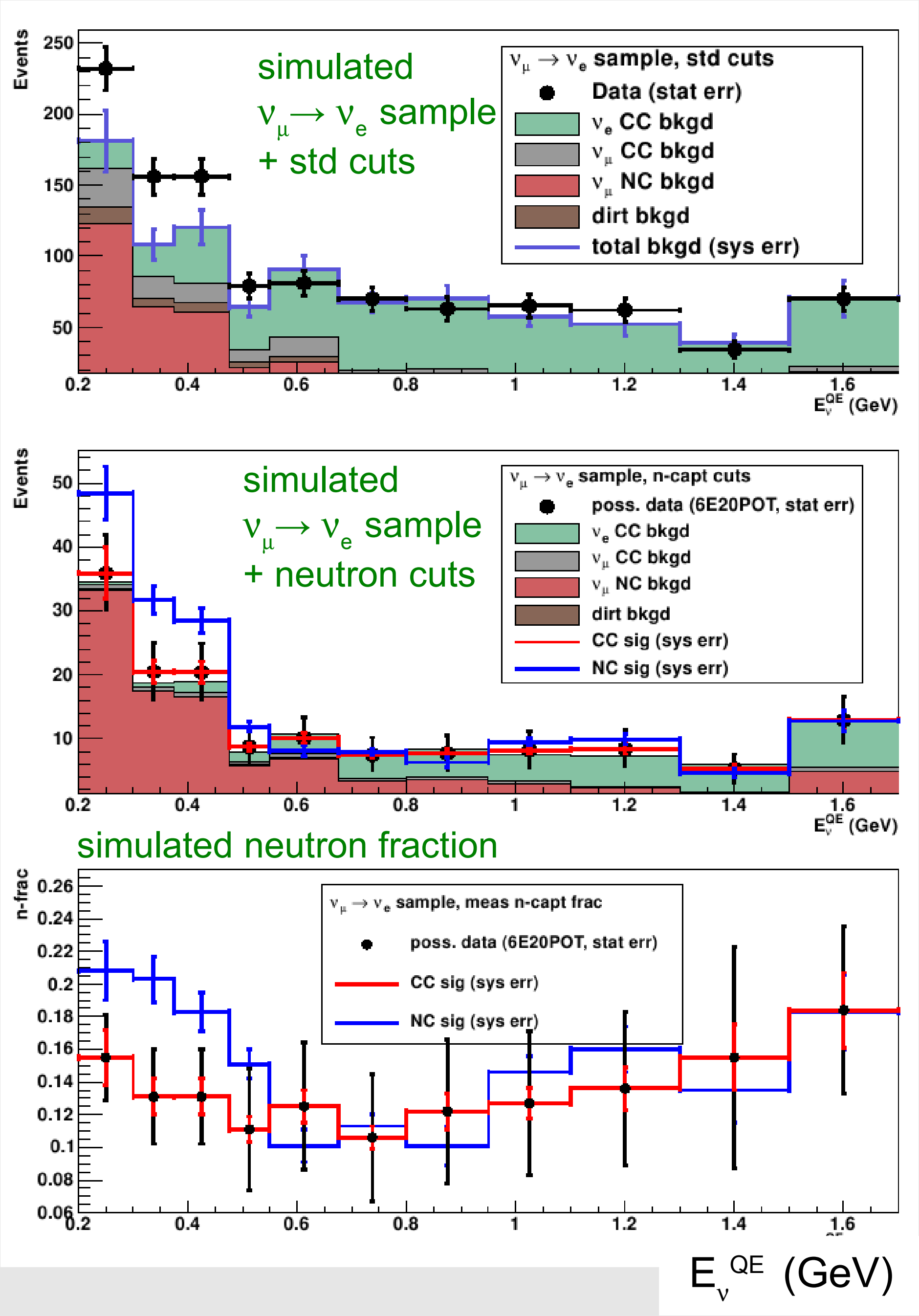
A new oscillation analysis of MB with scintillator has been simulated:

Assumptions:
- Previous ν oscillation experiment performed with same cuts and same statistics (6.5E20POT)
  - reconstruction performance same as previous
  - same excess is seen in this analysis (top plot)

- Then n-capture events are required and a reduced data set is obtained (middle plot)

Assumptions:
  - excess is due to oscillations (CCQE events)
  - CC event n-fraction = 1%(250 MeV) - 10%(1GeV), includes final state effects and has been measured.
  - NC event n-fraction = 50%. From Δ dominance in both NCγ and NCπ^0
  - 50% n-capture efficiency
  - 2% accidental n-capture probability
  - systematic errors assigned to all these and variational studies performed.

Note that data excess disappears in middle plot and is same as CC prediction (red lines). If excess due to NC background (blue lines), then excess remains.



Simulated Analysis

If excess is CC oscillation signal, then separation from NC hypothesis is 3.5σ for this NC/CC test. Combined with expected neutrino-mode excess in 1st stage analysis (of 3.4σ) yields ~5σ

Variations of study assumptions performed.
- POT, statistics limited study, need 6.5E20POT
- background rejection important to achieve sensitivity.

	neutron fraction			
configuration	NC prediction	fake data	difference	$n\sigma$
standard	0.191 ± 0.008	0.134 ± 0.015	0.057 ± 0.016	**3.48**
4E20POT	0.191 ± 0.008	0.134 ± 0.018	0.057 ± 0.019	2.95
2E20POT	0.191 ± 0.008	0.134 ± 0.026	0.057 ± 0.027	2.16
(bckgnd error)×0.5	0.191 ± 0.005	0.134 ± 0.015	0.057 ± 0.015	3.73
(n-capture efficiency)=0.75	0.277 ± 0.012	0.191 ± 0.018	0.086 ± 0.021	4.13
(accidental efficiency)×2	0.211 ± 0.008	0.154 ± 0.016	0.057 ± 0.017	3.29
(CC n-fraction)×2	0.191 ± 0.008	0.137 ± 0.015	0.054 ± 0.017	3.26
(low-E CC n-fraction)=0.06	0.199 ± 0.008	0.147 ± 0.015	0.051 ± 0.017	3.00
(NC n-fraction error)×2	0.191 ± 0.010	0.134 ± 0.015	0.057 ± 0.017	3.31
dirt n-fraction=0.5	0.203 ± 0.008	0.145 ± 0.015	0.057 ± 0.017	3.32
(NC bckgnd)×2	0.215 ± 0.011	0.175 ± 0.014	0.040 ± 0.017	2.29
(NC bckgnd)×2 + ∞ POT	0.215 ± 0.011	0.175 ± 0.000	0.040 ± 0.010	3.81
(NC n-fraction)= 0.42	0.165 ± 0.006	0.117 ± 0.014	0.048 ± 0.015	3.17
∞ POT	0.191 ± 0.008	0.134 ± 0.000	0.057 ± 0.008	7.63

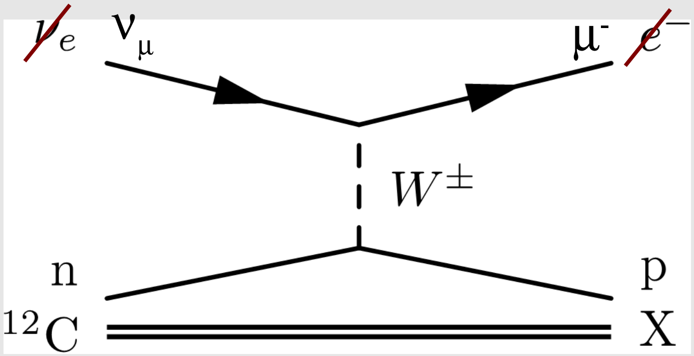
Calibration of signal/background n-fraction

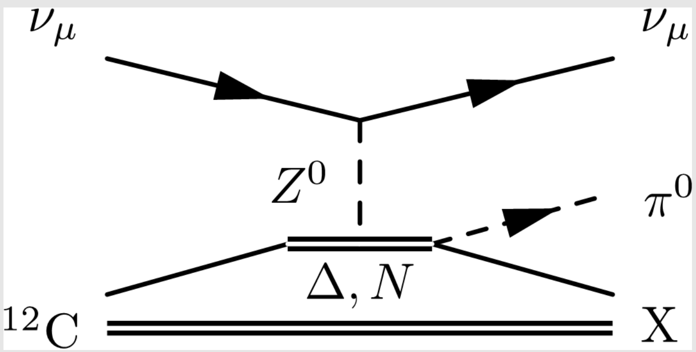
Assumed n-fraction in CC/NC is very important component of this analysis.
Numbers here have been estimated from previous data and model guidance.

In actual experiment they will be *measured.*

- For ν_e CCQE interactions, can measure n-fraction in ν_μ CCQE events

- For ν_μ NC backgrounds, ν_μ NCπ^0 events (with well-identified) π^0 will be used





Results in measured n-fraction for both CC signal and NC background, bin-bin in reconstructed ν energy.
These measurements include final state effects.

Run Plan/Future work

This proposed measurement requires 6.5E20POT.
Assuming that 2E20POT/year available on Booster neutrino beamline (with MicroBooNE)

Then:
- add scintillator in early 2014 (after MB dark-matter search)
- run 2E20POT/yr 2014-2016 concurrently with MicroBooNE.

Before we are ready to submit full proposal, these tasks need to be done:

- demonstrate that adequate PID is possible with scintillator
- more work on light model in MC
- additional light output tests in lab
- attenuation length tests
- material compatibility tests
- scintillator procurement plan and further price estimates
- scinitillator mixing and recirculation plan

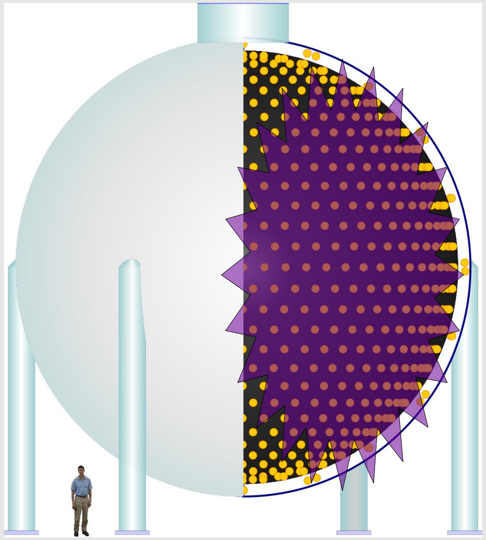
Summary

The addition of scintillator to MiniBooNE will open a new research opportunity at Fermilab for in near term (3-4 years).

This modest additional investment into MiniBooNE allows these physics topics
- NC/CC test of low-energy ν oscillation excess,
- nucleon spin structure measurement, Δs, via NC elastic scattering,
- measurement of $\nu_\mu C \rightarrow \mu^- N_{g.s.}$ and low-energy flux test,
- test of the quasielastic assumption in ν energy reconstruction.

These will come with associated publications and 4-6 Ph.D. theses.

Exciting new physics, results in timely manner.



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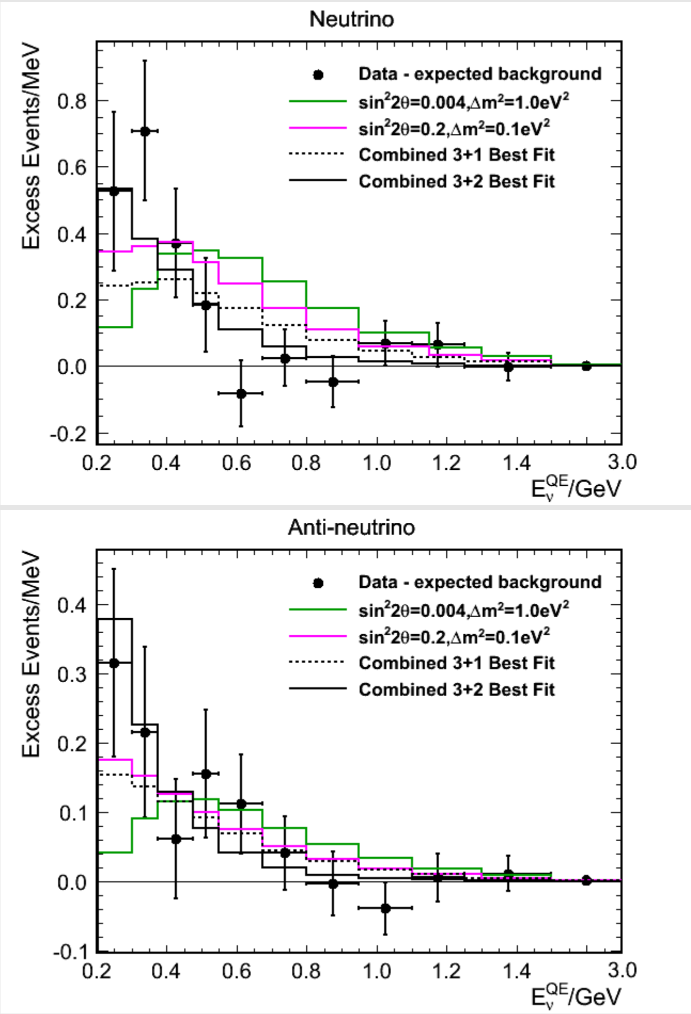
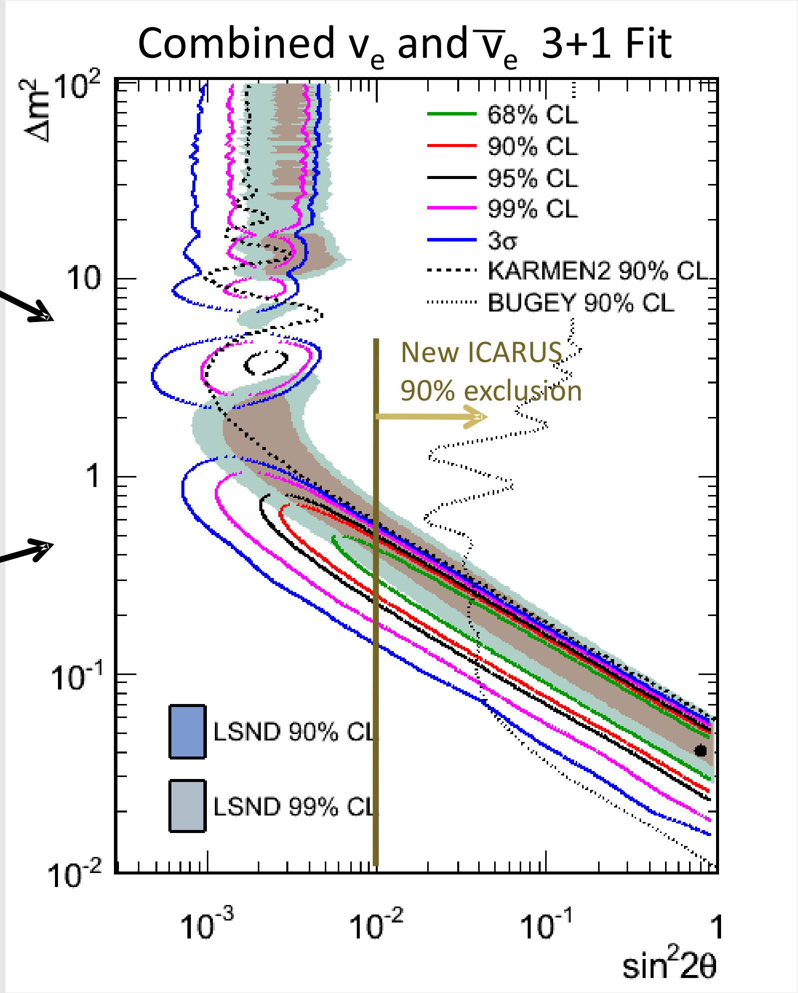
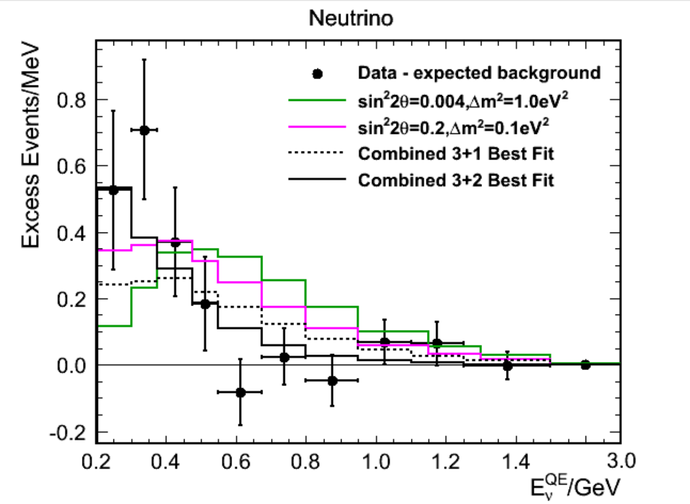
Backup slides

Ten Years of MiniBooNE Running: Oscillation Results



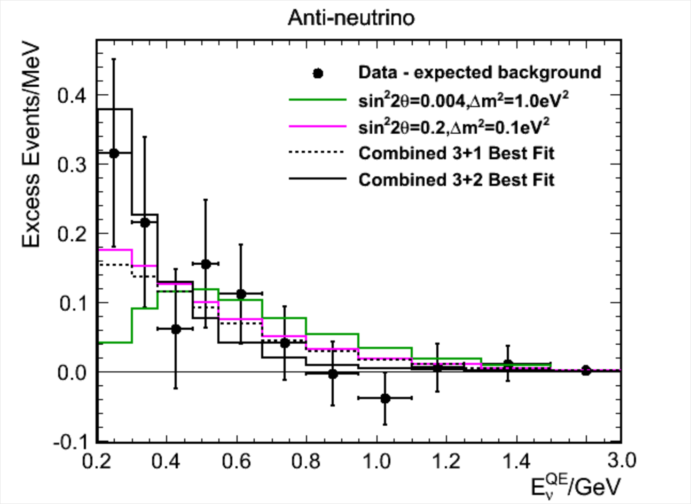


- Combined ν_e and $\overline{\nu}_e$ Event Excess from 200-1250 MeV = 240.3+-34.5+-52.6 (3.8σ)



6.7e20 POT neutrino mode

ν mode	E > 200 MeV	E > 475 MeV
χ^2(null)	22.81	6.35
Prob(null)	0.5%	36.6%
χ^2(bf)	13.24	3.73
Prob(bf)	6.12%	42.0%



11.3e20 POT anti-neutrino mode

$\bar{\nu}$ mode	E > 200 MeV	E > 475 MeV
χ^2(null)	16.3	7.59
Prob(null)	5.8%	26.4%
χ^2(bf)	4.76	3.23
Prob(bf)	67.5%	50.2%